Precise Measurement of the Spin-Dependent Transverse Asymmetry in Quasielastic $^3\vec{\mathrm{He}}(\vec{\mathrm{e}},\mathrm{e}')$ and the Neutron Magnetic Form Factor

J.-O. Hansen
for the Jefferson Lab E95-001 Collaboration

Jefferson Lab, 12000 Jefferson Avenue, Newport News, Virginia 23606

Abstract. We report a measurement of the transverse asymmetry $A_{T'}$ in $^3\vec{\mathrm{He}}(\vec{e},e')$ quasielastic scattering with high statistical and systematic precision at Q^2-values from 0.1 to 0.6 (GeV/c)^2. Using a state-of-the-art Faddeev calculation, the neutron magnetic form factor G_M^n is extracted for $Q^2 = 0.1$ and 0.2 (GeV/c)^2 with an experimental uncertainty of less than 2%. The results are in excellent agreement with those recently obtained at NIKHEF and Mainz using a deuterium target.

INTRODUCTION

The electromagnetic form factors of the nucleon have been a long-standing subject of interest in nuclear and particle physics. They describe the distribution of charge and magnetization within nucleons and thus allow sensitive tests of nucleon models and Quantum Chromodynamics at low energies.

The neutron form factors are known with much less precision than the proton form factors because of the lack of free neutron targets. As experimental capabilities have improved over the past decade, much effort has been directed towards increasing the precision of the neutron data. Considerable attention has been devoted to the precise measurement of the magnetic form factor, G_M^n [1].

Until recently, most data on G_M^n had been deduced from elastic and quasielastic (QE) electron-deuteron scattering [2–5]. By measuring the ratio of the $d(e,e'n)$ to $d(e,e'p)$ cross sections at QE kinematics, uncertainties in G_M^n of 1–3% have been achieved [3–5]. Unfortunately, there is a significant disagreement between these results (cf. Fig. 2), and further data are desirable to help clarify the situation.

Precision data on G_M^n can also be obtained from the inclusive reaction $^3\vec{\mathrm{He}}(\vec{e},e')$ at QE kinematics. In comparison to deuterium experiments, this technique employs a different target and relies on polarization degrees of freedom. It is thus subject

TABLE 1. Kinematics of the quasielastic measurements.

Q^2	$(\mathrm{GeV/c})^2$	0.1	0.193	0.3	0.4	0.5	0.6
E	(GeV)	0.778	0.778	1.727	1.727	1.727	1.727
E'	(GeV)	0.717	0.667	1.559	1.506	1.453	1.399
θ	(deg)	24.44	35.50	19.21	22.62	25.80	28.85

to completely different systematics. Pilot experiments using this technique were carried out in 1990-93, and a result for G_M^n was extracted [6]. In this talk, we report the first precision measurement of G_M^n using a polarized ^{3}He target [7].

Polarized ^{3}He is useful for studying the neutron electromagnetic form factors because of its unique spin structure: The ^{3}He ground state is dominated by a spatially symmetric S wave in which the proton spins cancel and the spin of the ^{3}He nucleus is carried by the unpaired neutron [8]. In electron scattering, the spin-dependent properties of ^{3}He can be studied by measuring the spin-dependent asymmetry, defined as $A \equiv (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$, where the subscript $+(-)$ refers to the helicity of the incident electrons, and σ is the differential cross section. In terms of nuclear response functions R_k, the asymmetry can be written [9]

$$A = -\frac{\cos\theta^* \nu_{T'} R_{T'} + 2\sin\theta^* \cos\phi^* \nu_{TL'} R_{TL'}}{\nu_L R_L + \nu_T R_T}, \quad (1)$$

where the ν_k are kinematic factors, and θ^* and ϕ^* are the polar and azimuthal angles of target spin with respect to the 3-momentum transfer vector $\mathbf{q}$. By orienting the target spin at $\theta^* = 0$, *i.e.* parallel to $\mathbf{q}$, one selects the transverse asymmetry $A_{T'}$ (proportional to $R_{T'}$).

Because the ^{3}He nuclear spin is carried mainly by the neutron, $R_{T'}$ contains a dominant neutron contribution at the QE peak and is essentially proportional to $(G_M^n)^2$, similar to elastic scattering from a free neutron. This picture has been confirmed in several theoretical studies [10–12]. Thus, the inclusive asymmetry $A_{T'}$ in the vicinity of the ^{3}He QE peak is highly sensitive to $(G_M^n)^2$.

JEFFERSON LAB EXPERIMENT E95-001

The experiment was carried out in Hall A at the Thomas Jefferson National Accelerator Facility (JLab), using a longitudinally polarized continuous wave electron beam of 10 μA current incident on a high-pressure polarized ^{3}He gas target [14]. The target was polarized by spin-exchange optical pumping at a density of 2.5×10^{20} nuclei/cm^3 using rubidium as the spin-exchange medium. The beam and target polarizations were approximately 70% and 30%, respectively. The kinematics are detailed in Table 1.

Scattered electrons were observed in the two Hall A High Resolution Spectrometers, HRSe and HRSh. Both spectrometers operated in single-arm mode. The HRSe was set for QE kinematics while the HRSh detected elastically scattered

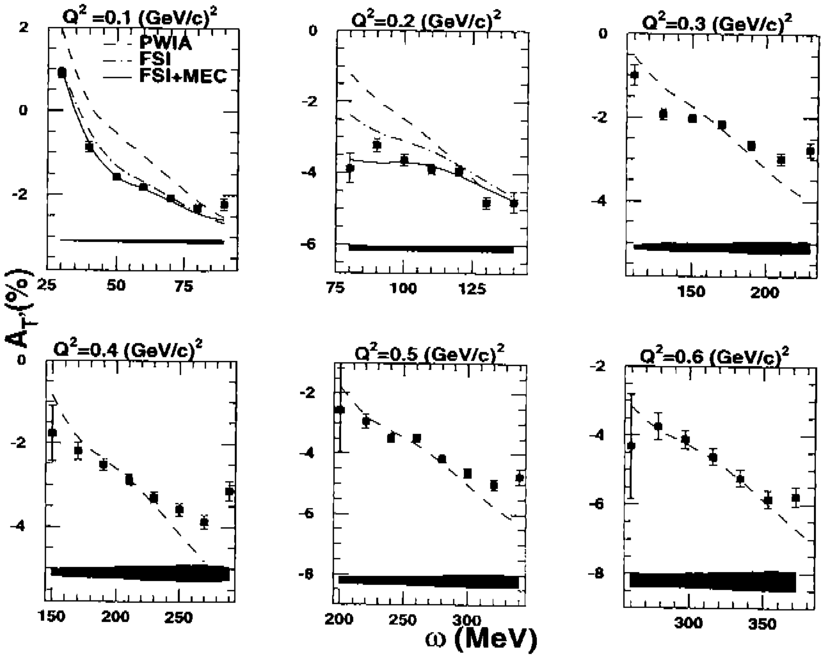

FIGURE 1. Results for the asymmetry $A_{T'}$ as a function of the electron energy transfer ω and the squared four-momentum transfer Q^2. The curves are explained in the text.

electrons. The elastic measurement allowed monitoring of the product of the beam and target polarizations, P_tP_b, with better than 3% precision. A more detailed description of the experiment and analysis has been published elsewhere [7].

The measured asymmetries $A_{T'}(\omega)$ are shown in Fig. 1. The error bars indicate the statistical uncertainty. The total experimental systematic uncertainty is depicted as an error band in each panel and amounts to 2% for $Q^2 = 0.1$ and 0.2 (GeV/c)^2, dominated by the error in P_tP_b, and 5% for the remaining Q^2 values, dominated by the uncertainty in the radiative corrections.

Also shown in Fig. 1 are the results of several calculations: PWIA [11] (dashed lines), Faddeev with final-state interaction (FSI) corrections [12] (dash-dotted lines), and Faddeev with both FSI and meson-exchange current (MEC) corrections [13] (solid lines). The latter two calculations are non-relativistic. All theory results are based on the Höhler nucleon form factor parametrization [15] and were averaged over the spectrometer acceptances using a Monte Carlo simulation. The advanced calculations [12,13] are not available for $Q^2 > 0.2$ (GeV/c)^2 because relativistic corrections become too large in that regime for the results to be reliable.

EXTRACTION OF THE FORM FACTOR

To extract G_M^n for the two lowest Q^2 kinematics, predictions for $A_{T'}(G_M^n)$ were generated using the full Faddeev calculation [13] and averaged over a 30 MeV bin

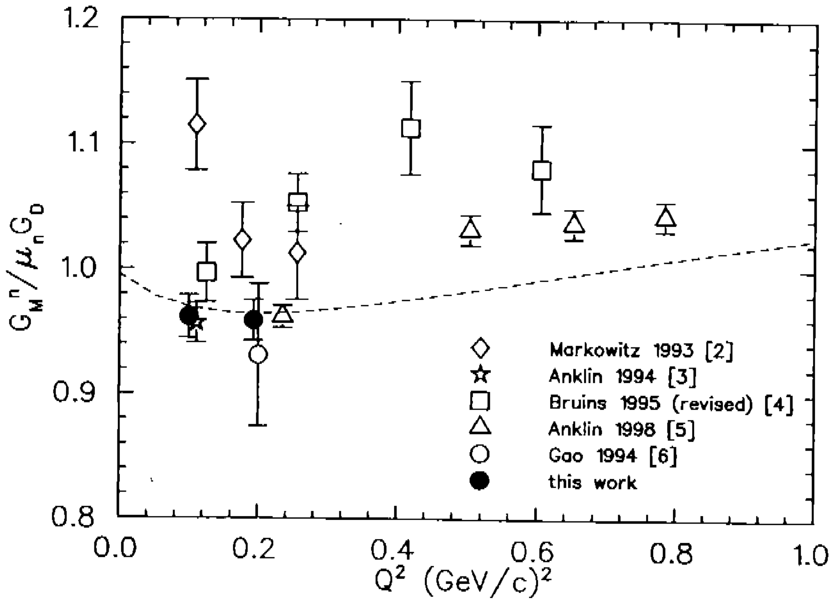

FIGURE 2. Recent results for the neutron magnetic form factor G_M^n in dipole units, $G_D = (1 + Q^2/0.71)^{-2}$. The dashed curve represents the Höhler parametrization [15].

around the QE peak. G_M^n was varied by multiplying the Höhler functional form with a constant factor. The extracted G_M^n corresponds to the value at the central Q^2 of each kinematics for which the predicted $A_{T'}$ agrees with the experimental number in the center 30 MeV bin. Our results are given in Fig. 2 and Tab. 2. The error bars in the figure are the quadrature sum of the statistical and experimental systematic uncertainties. Also shown in Fig. 2 are the results of the recent deuterium experiments [2–5]. As can be seen, our data are in agreement with those recently measured by Anklin *et al.* [3,5] at NIKHEF and Mainz.

The theoretical uncertainty in extracting G_M^n was estimated [7] to be 1.9% and 2.6% at $Q^2 = 0.1$ and 0.2 (GeV/c)^2, respectively, dominated by MEC and relativistic corrections. These uncertainties can be reduced once fully relativistic calculations become available and MEC corrections are further improved.

To extract G_M^n from our asymmetry data at $Q^2 = 0.3$ to 0.6 (GeV/c)^2, a fully relativistic 3-body calculation that includes FSI and MEC corrections is required, which is presently not at hand. Efforts are underway to extend the full calculation [13] to higher Q^2 [16].

TABLE 2. Extracted values for G_M^n. The uncertainties are statistical and experimental systematic, respectively.

Q^2 (GeV/c)^2	$G_M^n/G_M^n(Dipole)$	Uncertainties
0.1	0.962	±0.014 ±0.010
0.2	0.959	±0.013 ±0.010

CONCLUSIONS

In conclusion, we have measured the asymmetry $A_{T'}$ in inclusive QE $^3\vec{\mathrm{He}}(\vec{e},e')$ scattering at Q^2-values from 0.1 to 0.6 (GeV/c)^2 with very high precision. The neutron magnetic form factor G_M^n has been extracted at $Q^2 = 0.1$ and 0.2 (GeV/c)^2 with $\lesssim$2% experimental accuracy. Our G_M^n data agree with the recent measurements of Anklin *et al.* [3,5] on deuterium. The present experiment provides the first precision data on G_M^n using a fundamentally different experimental approach than previous experiments. Thus it is a significant step towards understanding the discrepancy among the existing data sets in the low-Q^2 region.

ACKNOWLEDGEMENTS

We thank the Hall A technical staff and the JLab Accelerator Division for their outstanding support during this experiment. This work was supported in part by the U.S. Department of Energy under contract no. DE-AC05-84ER40150 (JLab) and other grants, DOE/EPSCoR, the U.S. National Science Foundation, the Science and Technology Cooperation Germany-Poland and the Polish Committee for Scientific Research, the Ministero dell'Università e della Ricerca Scientifica e Tecnologica, the French Commissariat à l'Énergie Atomique, Centre National de la Recherche Scientifique, and the Italian Istituto Nazionale di Fisica Nucleare. Numerical calculations were performed at the U.S. National Energy Research Scientific Computer Center (NERSC) and at the NIC in Jülich.

REFERENCES

1. H. Gao, plenary talk, SPIN2000, these proceedings.
2. P. Markowitz *et al.*, *Phys. Rev. C* **48**, R5 (1993).
3. H. Anklin *et al.*, *Phys. Lett.* **B336**, 313 (1994).
4. E.E.W. Bruins *et al.*, *Phys. Rev. Lett.* **75**, 21 (1995); B. Schoch, priv. comm.
5. H. Anklin *et al.*, *Phys. Lett.* **B428**, 248 (1998).
6. H. Gao *et al.*, *Phys. Rev. C* **50**, R546 (1994); *Nucl. Phys.* **A631**, 170c (1998).
7. W. Xu *et al.*, *Phys. Rev. Lett.* **85**, 2900 (2000).
8. B. Blankleider and R.M. Woloshyn, *Phys. Rev. C* **29**, 538 (1984).
9. T.W. Donnelly and A.S. Raskin, *Ann. Phys. (N.Y.)* **169**, 247 (1986).
10. R.-W. Schulze and P. U. Sauer, *Phys. Rev. C* **48**, 38 (1993).
11. A. Kievsky, E. Pace, G. Salmè, M. Viviani, *Phys. Rev. C* **56**, 64 (1997).
12. S. Ishikawa *et al.*, *Phys. Rev. C* **57**, 39 (1998).
13. V.V. Kotlyer, H. Kamada, W. Glöckle, J. Golak, *Few-Body Syst.* **28**, 35 (2000).
14. J.S. Jensen, Ph.D. Thesis, California Institute of Technology, 2000 (unpublished).
15. G. Höhler *et al.*, *Nucl. Phys.* **B114**, 505 (1976).
16. W. Glöckle, private communication.